

THE IMPACT OF CO₂-BASED DEMAND-CONTROLLED VENTILATION ON ENERGY CONSUMPTIONS FOR AIR SOURCE HEAT PUMPS IN SCHOOLS

Nihal AlRaees
Graduate Student

Nabil Nassif, Ph.D. P.E.
Assistant professor

Department of CAAE Engineering
North Carolina A&T State University
Department of CAAE Engineering
Greensboro, NC, USA

ABSTRACT

There have been increasingly growing concerns for many years over the quality of the air inside buildings and the associated energy use. The CO₂-based demand-controlled ventilation DCV offers a great opportunity to reduce energy consumption in HVAC systems while maintaining the ventilation requirements. Thus, the paper discusses the applications of CO₂-based demand-controlled ventilation DCV strategy for air source heat pumps in schools, investigates its impact on the annual energy consumption, and determines the potential savings achieved in different USA locations. The study includes detailed energy analysis on an existing middle school through whole building simulation energy software. The simulation model is first calibrated and checked for accuracy using the actual monthly utility data. This model is then used for saving calculations resulted from CO₂-Based DCV and with various occupancy profiles and locations. The results show a significant saving could be obtained as compared to the actual operating strategy implemented in the existing system and this saving depends mainly on the actual occupancy profile and building locations.

INTRODUCTION

Ventilating the building with a fresh air to maintain a proper indoor air quality (IAQ) is one of the major loads added to the HVAC system, as in some cases up to 30% in office buildings (Chao and Hu 2004; Shan et al. 2012). School buildings has much more concerns about IAQ due to the fact that schools present much higher occupancy per area than other buildings and children spend 12% of their life time in classrooms (Santamouris et al 2008).

Controlling ventilation is recommended to maintain the minimum airflow rate that specified by ASHRAE standard 62.1 2010 (ASHRAE standard 62.1 2010) and avoid over ventilating to reduce energy consumption in buildings (Wang and Xu 2002; Nassif 2012; Shan et al 2012). Many ventilation control strategies are proposed for HVAC system (Nassif et al 2005; Lu et al 2011; Mysen et al 2005; Ng et al 2011). CO₂-based demand control ventilation (CO₂-DCV) is one of the strategies that that could lower energy use by reducing over-ventilation of buildings (Nassif 2012, Taylor 2006, and Stanke 2006). Most DCV strategies are based on flow rate per person, which may not necessary comply with the new ventilation requirements of ASHRAE Standard 62.1 2010 (ASHRAE Standard 62.1 2010). As the new standard requires two ventilation rates, one intended to dilute the contaminants generated by occupants and other for building-related sources, the required space CO₂ concentration or the indoor-outdoor difference is no longer constant, making any CO₂-based DCV strategy hard to apply (Stanke 2006, Murphy 2005, Nassif 2012). This paper discusses the applications of CO₂-based demand-controlled ventilation DCV strategy for air source heat pumps in schools, investigates its impact on the annual energy consumption, and determines the potential savings achieved in different USA locations. The methodology used in this study includes (1) modeling an existing middle school located in North Carolina, equipped with a total of forty nine wall mounted air source heat pumps, using the whole building simulation energy software eQuest, (2) comparing the energy consumptions simulated by the model with the actual monthly

energy data collected over five years for model calibration and testing for the accuracy, and (3) running the validated model with CO₂-based demand-controlled ventilation DCV for different occupancy profiles and USA ASHRAE climate zones to estimate the energy savings as compared to the actual existing operating strategy.

CO₂-BASED DEMAND-CONTROLLED VENTILATION

A 133,200 ft² middle school located in North Carolina (near the city of Greensboro) is used for this study. There are a total of forty nine wall mounted air source heat pumps located in classrooms. The capacities of heat pumps vary from 2 to 4 tons, with airflow rates ranging from 800 to 1400 cfm. There are 27 direct-expansion DX coil units supplying conditioned air to offices, gyms and other general areas. The airflow rates of those units range from 600 and 8000 cfm.

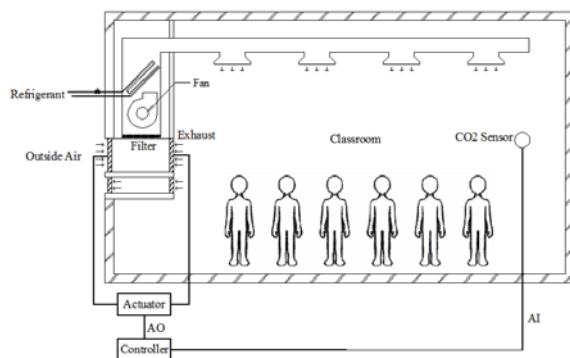


Figure 1. Schematic of air source heat pump located in the class room

Figure 1 shows a schematic of air source heat pump located in each class room. A fixed amount of fresh is supplied to the space based on design number of students. Thus, this study will investigate the energy benefits of using the CO₂-based DCV, which can be done by installing modulated damper, CO₂ sensor and controller. The CO₂ sensor can be installed on the wall in the class room, just like the thermostat. The controller will use the CO₂ signal to control and modulate the position of outdoor air damper and thereby provide the space with the proper amount of ventilation air. Two possible CO₂ control approaches could be used (a) proportional control

based on the calculations in Appendix A of the ASHRAE 62.1-2010 user's manual (ASHRAE Standard 62.1 2010) or (b) single set point control as described by Murphy (Murphy 2005).

MODELLING

An energy simulation software eQuest is used for the energy performance analysis. The detailed information on building and system was entered into the software and then the model outputs are compared with the actual data from utility bills. The model was first calibrated using the data of year 2009 and then tested for other four years (2007, 2008, 2010, and 2011). Figure 2 shows the comparison between the simulated and utility data for 2009. A calibration process began in order to reduce the error between the actual data and model outputs. Detailed information on schedule, equipment, lighting, etc. was collected and readjusted. The main adjustment was related to different occupant and equipment schedules due to different days and seasons. As example, summer, winter, holiday, weekday, weekend, and so on. Our stopping criteria are to obtain an error of 5% or less. The resulted error by comparing annual consumption between the model and utility data is 0.6%. However, as shown in Figure 2, by comparing the energy consumption per season, the errors are still within the 5%, for instance, 1.2% in winter, 4% in spring, 2.4% in summer, and 3.5% in fall.

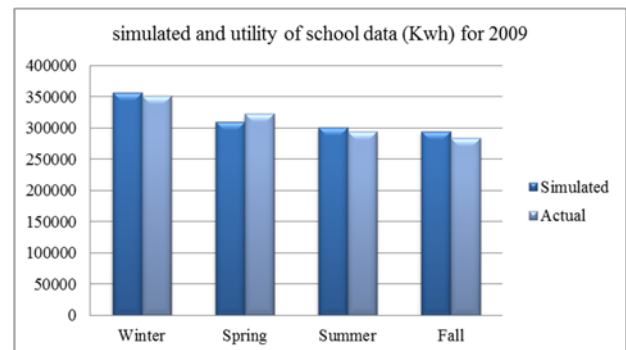


Figure 2. Comparison between the simulated and utility data for 2009

After the model was calibrated using the utility data of 2009, the model is then tested for other four years (2007, 2008, 2010, and 2011). Figure 3 shows comparison between the simulated and utility data for

those five years. The model errors are 2.3% for 2007, 8.2% for 2008, 0.6% for 2009 (calibrated period), 9% for 2010, and 6.5% for 2011. It noted that the model is overestimated the energy use for 2010 and 2011. After discussion with the school facility people we found that some energy conservations have been applied and the energy consumption drops due to these changes. The model produces better result and the error drops to less than 3% by adjusting to those changes (e.g. the major changes are related to equipment scheduling). Thus, the model uses in next section for energy saving calculations.

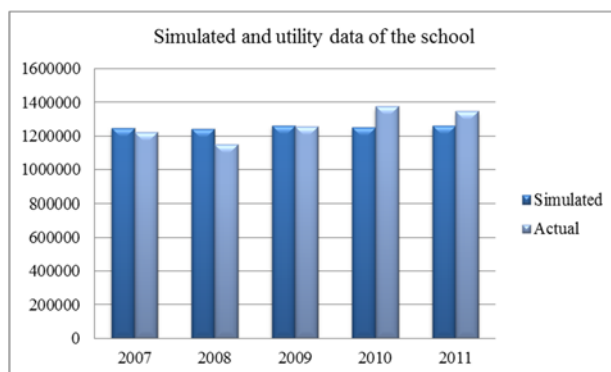


Figure 3. Comparison between the simulated and utility data for five years

RESULTS

The calibrated model developed by eQuest and discussed before is used for estimating the energy savings that could be resulted by implementing the CO₂-based DCV on heat pumps located in classroom and offices. As they are currently installed in the investigated school, the outdoor air intake provides a fixed amount of fresh air based on design number of students. Even if the outside air is suitable for free cooling, the system always provides this amount of air as there is no modulated damper and associated control installed. To demonstrate the energy saving from implementing the DCV, it is assumed that the occupancy profile varies from 100% as low as 50%. Figure 4 shows the annual cooling, heating, and total energy consumptions when the DCV is implemented with different occupancy profiles (100%, 90%, 80%, 70%, 60%, and 50% of design occupancy profile). The simulation is done for Greensboro, NC. The fan power is not included in the cooling and heating

energy consumption as shown in Figure 4 but it does in the total energy consumption. The baseline represents the case when the DCV is not implemented. When the occupancy is always at design condition as indicated by 100% and showed as a baseline, there is no saving obtained from DCV. However, when the occupancy is less than design condition for example, 90%, 80%, 70%, 60%, and 50%, the savings result are 6.3%, 9.7%, 13.1%, 16.5%, 19.8%, respectively. As indicated, when the DCV is integrated into the heat pump design, both energy cooling and heating consumptions drop significantly. As example, when the actual occupancy is 50% less than design one, the energy use drops from 316,000 kWh to 261,000 kWh for cooling, from 119,000 kWh to 66,000 kWh for heating, and from 1,258,000 kWh to 1,009,000 kWh for total building energy use.

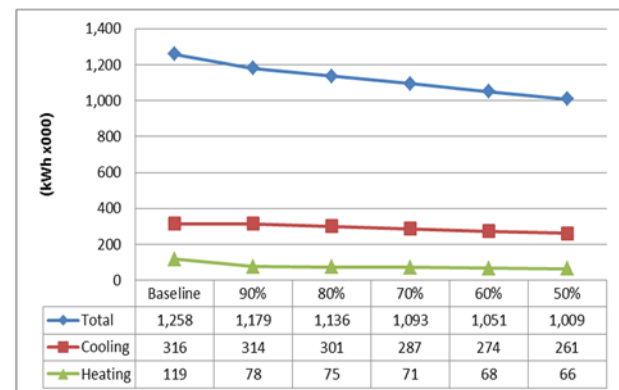


Figure 4. Annual cooling, heating, and total energy consumption resulted when the DCV is implemented with different occupancy profiles (Greensboro, NC)

The simulations are repeated for various USA locations covering most ASHRAE climate zones. Figure 5 shows the energy consumption and Figure 6 shows energy saving obtained by implementing the DCV in various USA locations. If the actual occupancy is 50% less than design value, the energy consumption drops from 1,345,100 kWh to 1,096,100 kWh, a saving of 18.5% in Las Vegas, for instance, and from 1,560,300 kWh to 1,317,700 kWh, a saving of 12.8% in Miami. A significant saving will be resulted by including the DCV with air source heat pumps in schools. The energy saving due to the DCV varies with locations and actual occupancy changes.

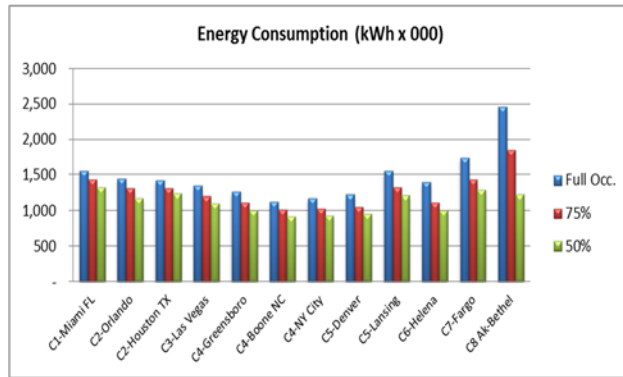


Figure 5. Energy consumption due to DCV implementation in various locations

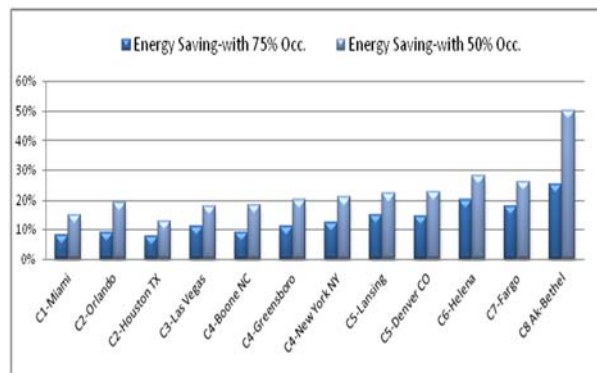


Figure 6. Energy saving due to DCV implementation in various locations

CONCLUSION

A 133,200 ft² middle school equipped with air source heat pumps is investigated in this study. The school is first modeled using the whole building simulation energy software eQuest. The model was calibrated using utility data of year 2009 and then tested on other utility data covering four years. The calibrated and tested results showed that the model produces accurate estimations and the error is less than 5%.

The model then uses to investigate the applications of CO₂-based demand-controlled ventilation DCV strategy for air source heat pumps in schools, investigates its impact on the annual energy consumption, and determines the potential savings achieved in different USA locations. By implementing the DCV, a significant energy savings can be achieved. The saving varies according to the locations and actual occupancy profile drifted from the design occupancy.

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